## 14.4 Enteric Fermentation—Greenhouse Gases

### 14.4.1 General

The description of this source is drawn from a report by Gibbs and Leng.[1] The methodology and factors presented in this section are drawn directly from the methodology description in the *State Workbook: Methodologies for Estimating Greenhouse Gas Emissions*, prepared by the U. S. EPA Office of Policy, Planning and Evaluation (OPPE),[2] *International Anthropogenic Methane Emissions: Estimates for 1990*,[3] and Crutzen, et al. (1986).[4] A more detailed discussion of biology and variables affecting methane ($CH_4$) generation from ruminant digestion can be found in those volumes.

Enteric fermentation is fermentation that takes place in the digestive systems of animals. In particular, ruminant animals (cattle, buffalo, sheep, goats, and camels) have a large "fore-stomach," or rumen, within which microbial fermentation breaks down food into soluble products that can be utilized by the animal.[1,2] Approximately 200 species and strains of microorganisms are present in the anaerobic rumen environment, although only a small portion, about 10 to 20 species, are believed to play an important role in ruminant digestion.[5] The microbial fermentation that occurs in the rumen enables ruminant animals to digest coarse plant material that monogastric animals cannot digest.[a]

Methane is produced in the rumen by bacteria as a by-product of the fermentation process. This $CH_4$ is exhaled or belched by the animal and accounts for the majority of emissions from ruminants. Methane also is produced in the large intestines of ruminants and is expelled.[1,2]

There are a variety of factors that affect $CH_4$ production in ruminant animals, such as: the physical and chemical characteristics of the feed, the feeding level and schedule, the use of feed additives to promote production efficiency, and the activity and health of the animal. It has also been suggested that there may be genetic factors that affect $CH_4$ production. Of these factors, the feed characteristics and feed rate have the most influence.[2]

To describe $CH_4$ production by ruminant animals, it is convenient to refer to the portion of feed energy (food caloric value) intake that is converted to $CH_4$. Higher levels of conversion translate into higher emissions, given constant feed energy intake. Similarly, higher levels of intake translate into higher emissions, given constant conversion. There are, however, interactions between level of intake and conversion to $CH_4$, so these values are not independent.[1,2]

Methane production as a fraction of the animal's gross energy intake generally will decrease as daily intake increases for the same diet, but the actual quantity of $CH_4$ produced may increase due to the greater amount of fermentable material. Because of the complex relationship between the quantity of feed and the $CH_4$ yield percentage, emission factors and straightforward emission equations can be used for general approximations only. In cases where the animal type, feed quality, and feed quantity are narrowly characterized and matched to reliable $CH_4$ yield percent values, $CH_4$ emission factors are much more accurate. In addition, feed intake changes over time with animal performance. Periodic updates to the emission factors are required to reflect changes in animal management characteristics.

As a result of the various interrelationships among feed characteristics, feed intake, and conversion rates to $CH_4$, most well-fed ruminant animals in temperate agriculture systems will convert about 5.5-6.5 percent of their feed energy intake to $CH_4$. Given this range for the rate of $CH_4$ formation, $CH_4$ emissions

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[a] Monogastric animals have a single-chambered stomach, unlike the multi-chambered stomachs of ruminants. Examples of monogastric animals include swine, dogs, monkeys, and humans.

can be estimated based on the feed energy consumed by the animals. Because feed energy intake is related to production level (e.g., weight gain or milk production), the feed energy intake can be estimated for these regions based on production statistics.[1,2]

The rates of conversion of feed energy to $CH_4$ for non-ruminant animals are much lower than those for ruminants. For swine on good quality grain diets, about 0.6 percent of feed consumed is converted to $CH_4$. For horses, mules, and asses the estimate is about 2.5 percent. While these estimates are also uncertain and likely vary among regions, the global emissions from these species are much smaller than the emissions from ruminant animals. Consequently, the uncertainty in these values does not contribute significantly to the uncertainty in the estimates of total $CH_4$ emissions from livestock.[2,4]

## 14.4.2 Emissions

Given their population and size, cattle account for the majority of $CH_4$ emissions in the United States for this source category. Cattle characteristics and emissions vary significantly by region. Therefore, it was important to develop a good model for cattle which takes into account the diversity of cattle types and cattle feeding systems in the United States. The variability in emission factors among regions for other animals is much smaller than the variability in emission factors for cattle.[2]

The emission factors presented here were developed using a validated mechanistic model[b] of rumen digestion and $CH_4$ production for cattle feeding systems in the United States.[5] The digestion model estimates the amount of $CH_4$ formed and emitted as a result of microbial fermentation in the rumen. The model is linked to an animal production model that predicts growth, pregnancy, milk production, and other production variables as a function of digestion products. The model evaluates the relationships between feed input characteristics and animal outputs including weight gain, lactation, heat production, pregnancy, and $CH_4$ emissions.[5] The model has been validated for a wide range of feeding conditions encountered in the United States; a total of 32 diets were simulated for 8 animal types in 5 regions.[5] Figure 14.4-1 shows which states are assigned to each region. Table 14.4-1 provides regional emission factors for typical types of dairy and beef cattle. The use of these emission factors requires detailed information on cattle production characteristics.[2]

For example, emissions from beef cattle in Kansas from a 1,000 head (animal) operation using the yearling system are calculated using the figures and tables of this section, in the following manner:

$$EF = \frac{N * P}{2,000}$$

$$EF = \frac{(1,000 \text{ head}) \ (103.4 \text{ lb } CH_4/\text{head}-\text{yr})}{2,000 \text{ lb/ton}}$$

$$EF = 5.17 \text{ ton } CH_4/\text{year}$$

where: EF = $CH_4$ emission factor for a livestock operation or facility (ton $CH_4$/yr)

N = Number of animals of the operation (number or head)

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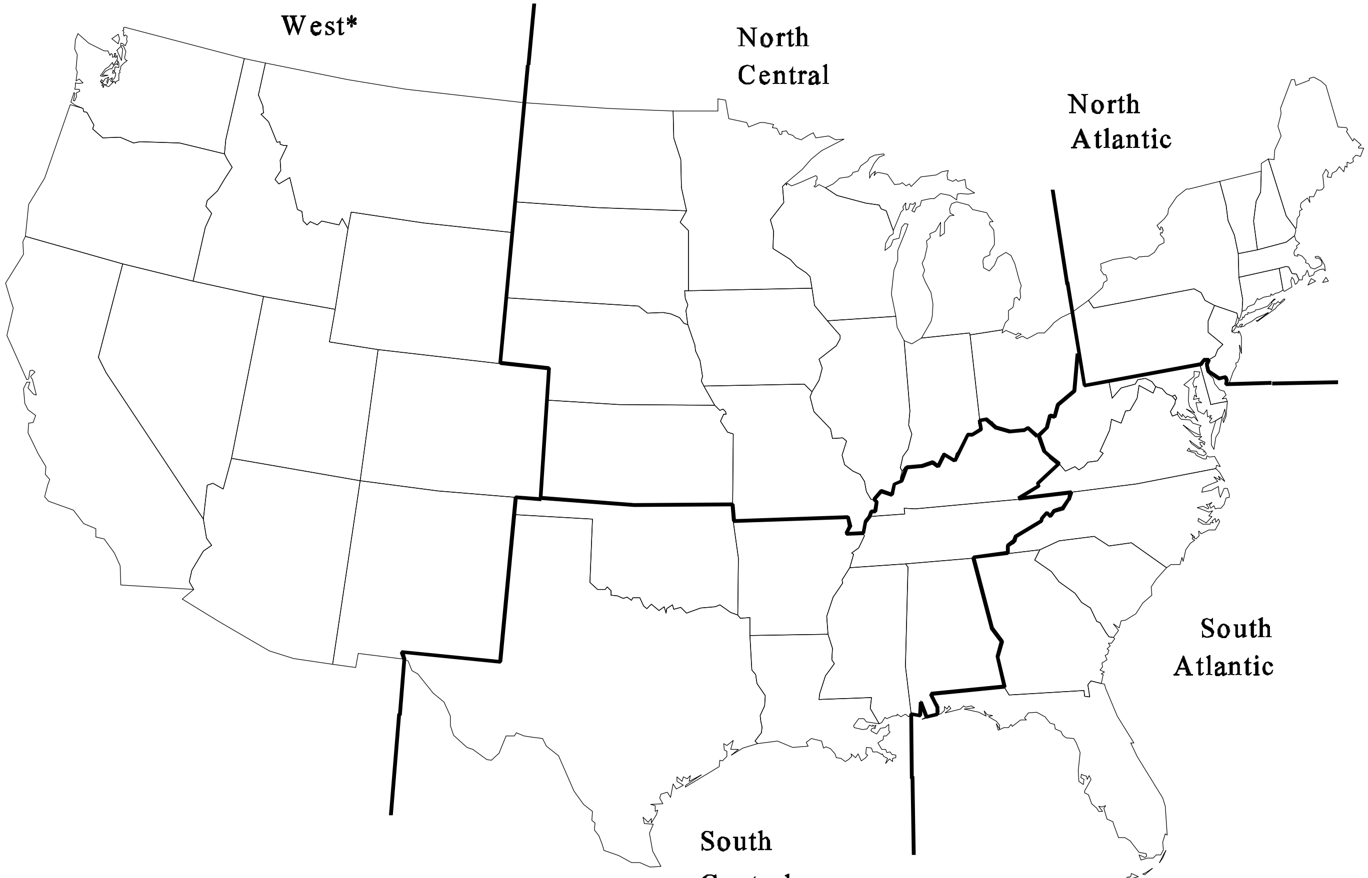
b The mechanistic model is outlined in the U. S. EPA Report to Congress entitled "Anthropogenic Methane Emissions in the United States: Estimates for 1990."[5]

F = the individual animal methane emission factor from Table 14.4-1 and Figure 14.4-1 (lb $CH_4$/head-yr). In this example Kansas is in the north central zone according to Figure 14.4-1 and yearling operations in the north central zone have an "F" value of 103.4 lb $CH_4$ per head-yr.

Emission factors for other animals were developed using a simple functional relationship between feed intake and feed intake released as $CH_4$.[3,4] This approach is reasonable given that feed characteristics of other animals are more or less homogeneous. Table 14.4-2 provides emission factors for sheep, goats, swine, horses, mules, and asses in developing and developed countries. Note that emission factors differ for sheep and swine for developed and developing countries, and the emission factor for water buffalos is unique for India.

Emission factors for cattle outside of the United States were also developed based on a model of feed intake and methane conversion. Table 14.4-3 provides emission factors for dairy cattle in Western Europe, Eastern Europe, Oceania, Latin America, Asia, Africa and the Middle East, and the Indian Subcontinent. Table 14.4-4 provides emission factors for non-dairy cattle in the same regions.

Although much study and measurement of this source has been done, the potential variation for the parameters used to develop the emission factors introduce a considerable amount of uncertainty, as would be the case for any source that relies on biological processes, which are highly variable by nature.




* Includes Alaska and Hawaii

Figure 14.4-1. Geographic Regions.[2]

Table 14.4-1. EMISSION FACTORS FOR U. S. CATTLE BY REGION[a]

EMISSION FACTOR RATING: E

| Animal Type/Region | English Emission Factors | | | | | | Metric Emission Factors | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | North Atlantic | South Atlantic | North Central | South Central | West | National Average[b] | North Atlantic | South Atlantic | North Central | South Central | West | National Average[b] |
| Dairy Cattle | | | | | | | | | | | | |
| Replacements 0-12 months[c] | 42.9 | 45.1 | 41.6 | 44.7 | 45.5 | 43.1 | 19.5 | 20.5 | 18.9 | 20.3 | 20.6 | 19.5 |
| Replacements 12-24 months[c] | 128.5 | 129.1 | 126.3 | 135.7 | 134.6 | 129.4 | 58.3 | 58.6 | 57.3 | 61.5 | 61.0 | 58.7 |
| Mature Cows | 258.5 | 278.3 | 240.7 | 257.7 | 262.5 | 252.1 | 117.2 | 126.2 | 109.2 | 116.9 | 119.1 | 114.3 |
| Beef Cattle | | | | | | | | | | | | |
| Replacements 0-12 months[c] | 42.2 | 49.9 | 44.8 | 51.9 | 49.9 | 49.1 | 19.1 | 22.6 | 20.3 | 23.5 | 22.6 | 22.3 |
| Replacements 12-24 months[c] | 140.4 | 148.5 | 133.8 | 148.9 | 142.7 | 143.0 | 63.7 | 67.4 | 60.7 | 67.5 | 64.7 | 64.9 |
| Mature Cows | 135.3 | 154.0 | 130.9 | 155.9 | 152.0 | 146.7 | 61.4 | 69.8 | 59.4 | 70.7 | 68.9 | 66.5 |
| Weanling System Steers/Heifers[d] | NA[e] | NA[e] | 49.7 | 52.8 | 51.7 | 50.8 | NA[e] | NA[e] | 22.5 | 23.9 | 23.4 | 23.0 |
| Yearling System Steers/Heifers[f] | NA | NA | 103.4 | 104.7 | 104.7 | 104.1 | NA[e] | NA[e] | 46.9 | 47.5 | 47.5 | 47.2 |
| Bulls | 220.0 | 220.0 | 220.0 | 220.0 | 220.0 | 220.0 | 99.8 | 99.8 | 99.8 | 99.8 | 99.8 | 99.8 |

[a] Units are lbs $CH_4$/head/year. Metric units are kg $CH_4$/head/year. Reference 5.

[b] National averages are weighted by regional populations as of 1990.

[c] A portion of the offspring are retained to replace mature cows that die or are removed from the herd (culled) each year. Those that are retained are called "replacements."

[d] In "weanling systems," calves are moved directly from weaning to confined feeding programs. This system represents a very fast movement of cattle through to marketing. Weanling system cattle are marketed at about 420 days of age (14 months).

[e] These cattle types are typically not found in the North Atlantic and South Atlantic regions. If desired, it is appropriate to use the national total emission factor for these regions.

[f] "Yearling systems" represent a relatively slow movement of cattle through to marketing. These systems include a wintering over, followed by a summer of grazing on pasture. Yearling system cattle are marketed at 565 days of age (18.8 months). If desired, it is appropriate to use the national total emission factor for these regions.

Table 14.4-2. ENTERIC FERMENTATION EMISSION FACTORS FOR OTHER ANIMALS[a]

EMISSION FACTOR RATING: E

| Animal Type | Emission Factors | | | |
|---|---|---|---|---|
| | Developing Countries (lbs) | Developing Countries (kg) | Developed Countries (lbs) | Developed Countries (kg) |
| Sheep | 11.0 | 5.0 | 17.6 | 8.0 |
| Goats | 11.0 | 5.0 | 11.0 | 5.0 |
| Swine | 2.2 | 1.0 | 3.3 | 1.5 |
| Horses | 39.6 | 18.0 | 39.6 | 18.0 |
| Mules/Asses | 22.0 | 10.0 | 22.0 | 10.0 |
| Water Buffalo | 116.8[b] | 53.0 | 127.9 | 58.0 |

[a] References 3 and 4. Units are lbs/head/year or kg/head/year.
[b] India only. Emission factor for developed countries applies to other developing countries.

Table 14.4-3. ENTERIC FERMENTATION EMISSION FACTORS FOR DAIRY CATTLE[a]

EMISSION FACTOR RATING: E

| Region | $CH_4$ Emission Factor (lb/head/yr) | $CH_4$ Emission Factor (kg/head/yr) | Average Milk Production (lb/yr) | Average Milk Production (kg/yr) |
|---|---|---|---|---|
| Western Europe | 220 | 100 | 9240 | 4200 |
| Eastern Europe | 178 | 81 | 5610 | 2550 |
| Oceania | 150 | 68 | 3740 | 1700 |
| Latin America | 125 | 57 | 1760 | 800 |
| Asia | 123 | 56 | 3630 | 1650 |
| Africa and Middle East | 72 | 36 | 1045 | 475 |
| Indian Subcontinent | 101 | 46 | 1980 | 900 |

[a] Reference 6.

Table 14.4-4. ENTERIC FERMENTATION EMISSION FACTORS FOR NON-DAIRY CATTLE[a]

EMISSION FACTOR RATING: E

| Type | $CH_4$ Emission Factors (lb/head/yr) | $CH_4$ Emission Factors (kg/head/yr) |
|---|---|---|
| Western Europe | | |
| Mature Males | 132 | 60 |
| Replacement/growing | 185 | 84 |
| Calves on milk | 0 | 0 |
| Calves on forage | 73 | 6.3 |
| Eastern Europe[b] | | |
| Mature Females | 163 | 73.7 |
| Mature Males | 143 | 65 |
| Young | 88 | 40.2 |
| Oceania[c] | | |
| Mature Females | 139 | 63.2 |
| Mature Males | 121 | 54.6 |
| Young | 86 | 38.8 |
| Latin America[d] | | |
| Mature Females | 128 | 58.2 |
| Mature Males | 125 | 56.7 |
| Young | 92 | 42.3 |
| Asia[e] | | |
| Mature Females — Farming | 106 | 48.3 |
| Mature Females — Grazing | 90 | 41.3 |
| Mature Males — Farming | 128 | 57.5 |
| Mature Males — Grazing | 97 | 44.3 |
| Young | 68 | 31.2 |
| Indian Subcontinent[f] | | |
| Mature Females | 68 | 30 |
| Mature Males | 90 | 46.1 |
| Young | 37 | 17 |
| Africa | | |
| Mature Females | 68 | 31.2 |
| Draft Bullocks | 88 | 39.7 |
| Mature Females — Grazing | 101 | 46 |
| Bulls — Grazing | 121 | 55.2 |
| Young | 31 | 14.2 |

[a] Reference 3.
[b] Based on estimates for the former U.S.S.R.
[c] Based on estimates for Australia.
[d] Based on estimates for Brazil.
[e] Based on estimates for China.
[f] Based on estimates for India.

References For Section 14.4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2. *State Workbook: Methodology For Estimating Greenhouse Gas Emissions*, EPA 230-B-92-002, U. S. Environmental Protection Agency, Office of Policy, Planning and Evaluation, Washington, DC, 1995.

3. *International Anthropogenic Methane Emissions: Estimates for 1990*, EPA-230-R-93-010. U. S. Environmental Protection Agency, Global Change Division, Office of Air and Radiation, Washington, DC, 1994.

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5. *Anthropogenic Methane Emissions In The United States: Estimates For 1990,* Report to Congress, U. S. Environmental Protection Agency, Office of Air and Radiation, Washington, DC, 1993.

6. *Greenhouse Gas Inventory Workbook,* Intergovernmental Panel On Climate Change/Organization For Economic Cooperation And Development, Paris, France, pp. 4.1-4.5, 1995.